2.9.1 Sample of Minneapolis Freeway Results

Run 02110625 is representative of heavy volume morning traffic flow into Minneapolis. The temperature at the start of the run was 18oF (-7.8oC). Light flurries fell during the run.

Figure 12 shows vehicle speed in lane 2 (left eastbound lane of I-394) versus time of day as fitted with a fifth-order polynomial to the actual data. The polynomial fit smoothes out the spiky, discrete nature of the actual speeds. The plotted speeds were calculated by averaging data from the TDN-30, Autoscope 2003, and a pair of inductive loops over 5-minute intervals. The three curves are consistent in their shape, with the only discernible difference being the magnitude of the speed. Speed was measured directly by the Whelen TDN-30 microwave detectors and output via an RS-232 interface to the data logger. The speeds calculated from the loops and the Autoscope VIP used the falling-edge time tag associated with each of two detection zones and knowledge of the spacings between those zones. The speeds noticeably decrease between 6:30 and 7:00 a.m. and resume free flow conditions between 9:30 and 10:00 a.m.

The lower speed calculated from timing of pulses generated by the two-loop speed trap is attributed to a pair of factors. The first is the sequential scanning feature used in the Detector Systems 222B loop driver electronics. The two loops (driven by a single, two-channel card) are alternately turned off and on so as to minimize interference due to crosstalk. This may have caused errors in recording the pulse timing that have a significant impact on the speed calculations. One can envision the lead loop being in the off state when a vehicle passes over it. Then when the loop is energized, the leading edge of the detection pulse does not necessarily correspond to the entrance of the vehicle into the loop's detection zone.

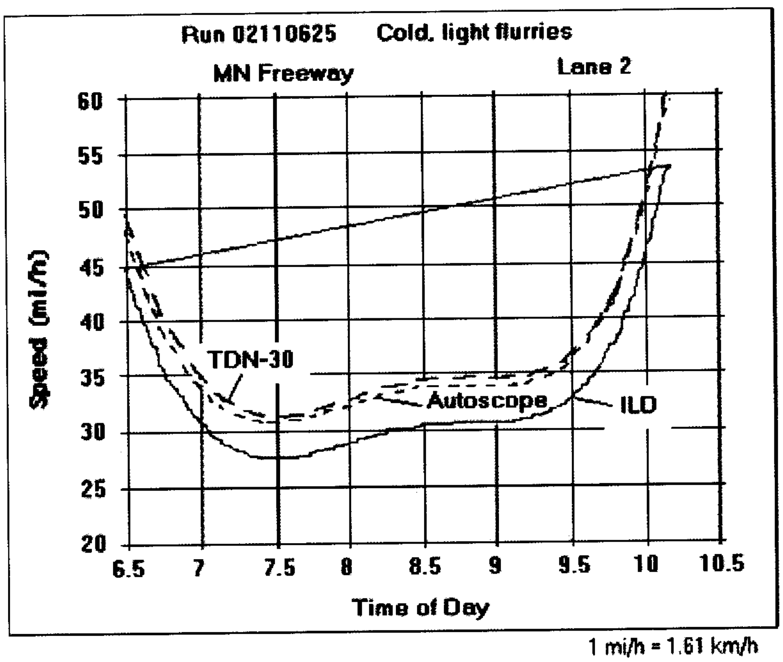


Figure 12. Comparison of speed data in lane 2 from I-394 Minneapolis freeway site

The second potential error contribution stems from the width of the vehicle detection pulse. According to the loop driver's specification, the pulse width is 125 ± 25 milliseconds. This pulse width (and the associated 20-percent uncertainty) is a significant fraction of the 170 milliseconds necessary for a vehicle traveling at a freeway speed of 60 mi/h (96.6 km/h) to traverse the 15-foot (4.6-m) center-to-center spacing between the two loops. The maximum percentage error in speed attributed to the pulse-width uncertainty for a vehicle traveling at 60 mi/h (96.6 km/h) is approximately 30 percent. The Traffic Analysis System (TAS) VIP was only operational at the Minnesota I-394 freeway site. Its performance is shown along with that of other detectors in Figures 13 and 14.

Figure 13 displays the vehicle counts from five detectors in lane 2 for a 1-hour ground truth interval during the heavy volume morning traffic flow. The counts from the Autoscope 2003 VIP, TAS VIP, TDN-30 narrow beam microwave Doppler detector, TC-30C ultrasonic detector, and the second 6-foot by 6-foot inductive loop in the lane (controlled by Detector System's 222B driver) during the 7:00 a.m. to 8:00 a.m. time interval were compared to the ground truth count tabulated manually from video imagery during the post-processing analysis. These detectors were installed to detect vehicles in a zone corresponding to overhead detectors with a 45-degree incidence angle. The counts from the five detectors were within 0.3 to 1.6 percent of the ground truth value in this heavy traffic volume run. The TAS VIP overcounted early in the hour and undercounted for the rest of the hour, resulting in a 98.8 percent overall count accuracy.

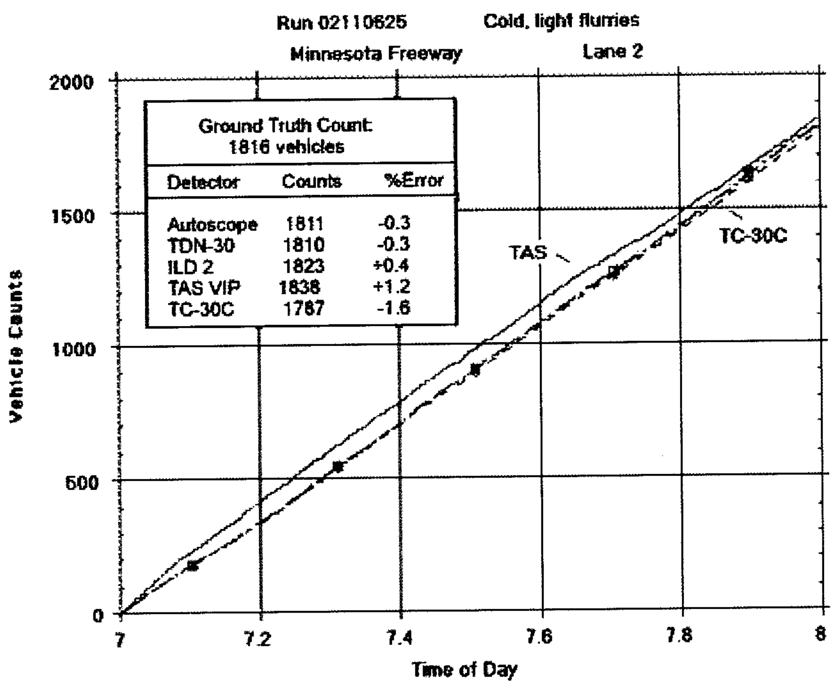


Figure 13. Detector vehicle counts and ground truth in lane 2 at I-394 Minneapolis freeway site

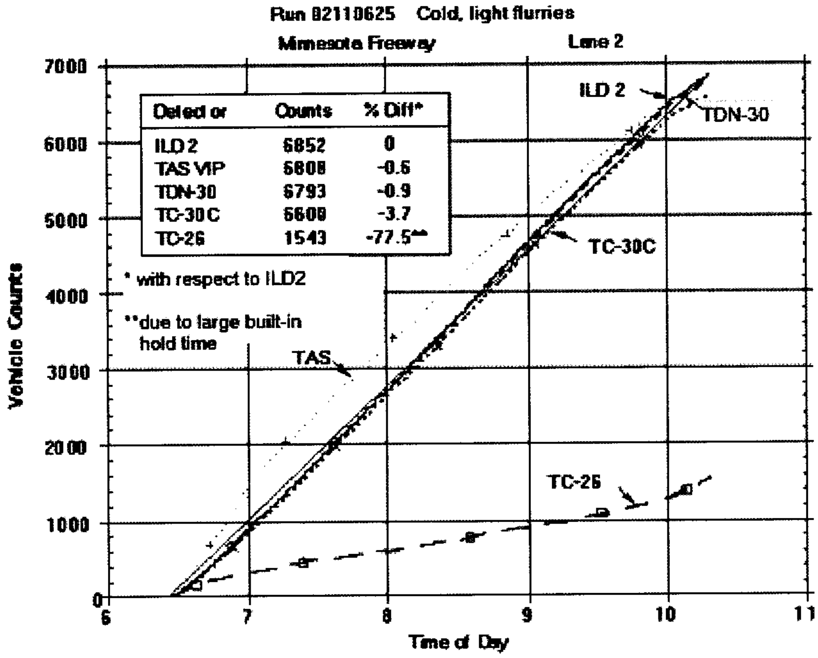


Figure 14. Detector vehicle counts over 4-hour run duration in lane 2 at I-394 Minneapolis freeway site

Figure 14 shows accumulated vehicle counts in lane 2 for the approximately 4-hour run duration. The counts from the TDN-30 and TC-26 Doppler microwave detectors, TC-30C ultrasonic detector, and TAS video image processor are compared with those from the second inductive loop in the lane. Percent differences were computed using the inductive loop count over the 4- hour interval as the reference.The TDN-30 count is within 0.9 percent of the loop, the TC-30C is within 3.7 percent, and the TAS is within 0.6 percent. The on time of the TC-30C averaged 0.29 second as compared to 0.14 second for the loop. The TC-26 significantly undercounted because of the long electronic hold time characteristic of this detector. The on time of the TC-26 averaged 5.47 seconds. The standard deviation of the TC-26 on time was 6.77 seconds and for the TC-30C it was 0.08 second.

The long hold time of the TC-26 caused missed detections when vehicles were closely spaced, such as in this heavy traffic volume run. The undercount is explained as follows. The TC-26 generates an electronic pulse when a vehicle is detected. If a second vehicle enters the detection zone before the falling edge of the original pulse occurs, then the TC-26 remains in the active state and does not detect the second vehicle as a separate event. Thus, an entire platoon of vehicles may trigger only a single detection pulse. The undercounting is more prevalent during heavy traffic when intervehicle gap times are at their minimum. The almost 5.5-second on time supports the hypothesis that the TC-26 is combining the detection of several vehicles into a single output count. The TAS VIP began the run overcounting vehicles until just after 7 a.m. This may be due to the VIP having difficulty transitioning from dark-to-light ambient lighting conditions. After this time, the TAS showed a tendency to undercount. The net result, a 99.4 percent counting accuracy with respect to the loop, requires explanation. Had the run ended earlier than approximately 10:20 a.m., the percent difference would have been greater because the undercount count interval would not have been long enough to compensate for the initial overcount interval. For example, if the run ended at 8 a.m., the TAS would show a percent difference of approximately +24 percent.

The TAS VIP tended to undercount, except during dark-to-light and light-to-dark transitions when it over-counted. The TAS does allow the operator to adjust a variety of setup and calibration parameters, a feature that theoretically should give more optimal performance in a true operational traffic management scenario. A factor that may have contributed to the observed performance of the TAS was the inability to position an ambient light monitoring zone sufficiently off the roadway due to the camera mounting height and location. Because of the zone's location, its ambient light monitoring function may have been affected by the headlights from oncoming vehicles.

2.9.2 Sample of Minneapolis Surface Street Results

This March 9 run was notable because of the appreciable amount of snowfall. The run was extended to 6 hours to gather as much data as possible under these conditions. Figure 15 shows vehicle count data output by the detectors in lane 2 (middle through lane on westbound Olson Highway) compared with ground truth obtained by manually counting the vehicles in lane 2 using the recorded video imagery from a 2-hour interval. The results appear within manufacturers' specifications.

2.9.3 Sample of Florida Freeway Results

The data from this July 28 run are representative of morning rush-hour conditions on westbound I-4 into Orlando. The session began at 6:15 a.m. and continued until approximately 10:50 a.m.

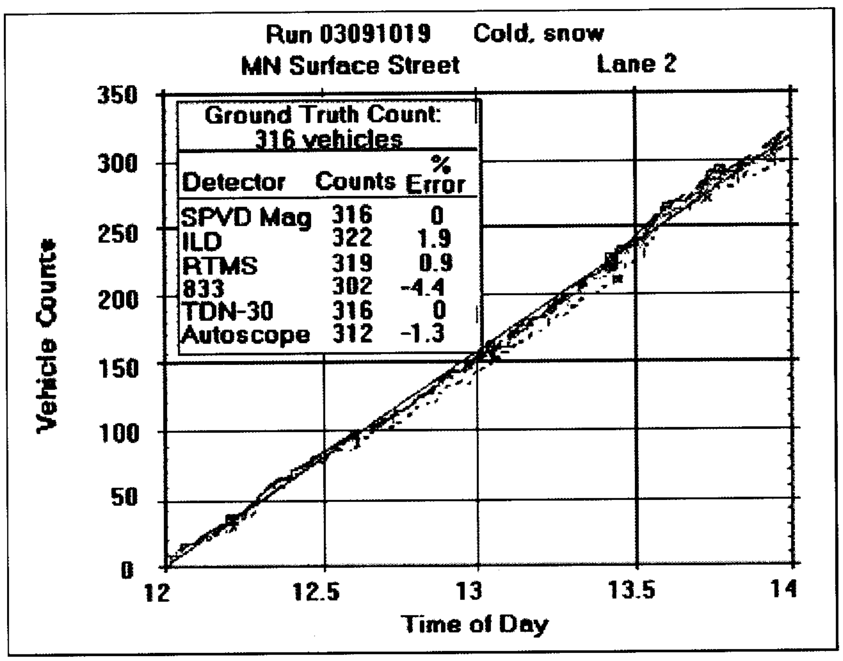


Figure 15. Comparison of detector vehicle counts with ground truth in lane 2 of the Olson Highway Minneapolis site

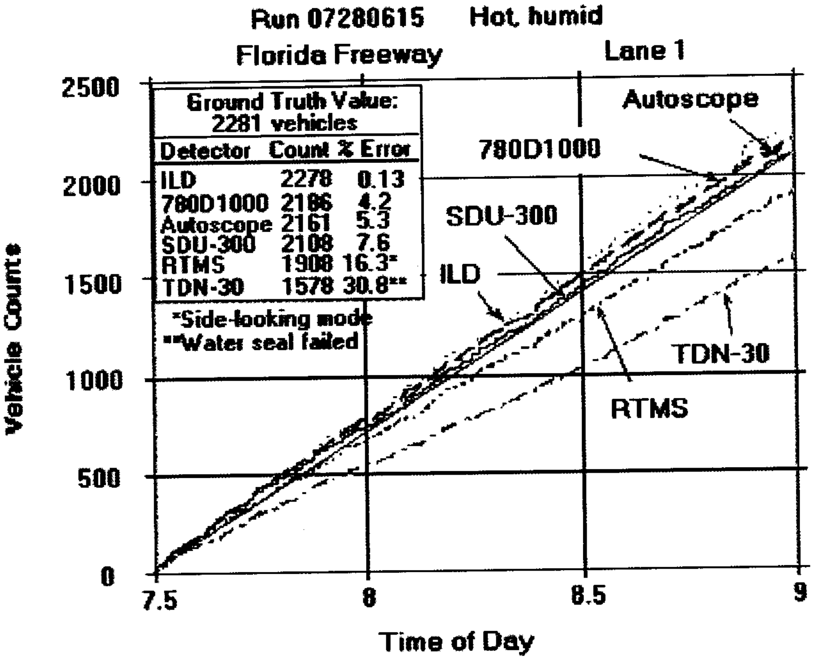


Figure 16. Comparison of detector count data at I-4 Florida freeway site

Figure 16 compares vehicle counts versus time of day for six traffic detectors located in the leftmost lane of the westbound I-4 freeway. Included are detectors that looked straight down (nadir looking) to those that monitored traffic flow 27 feet (8.2 m) further downstream. Vehicle count ground truth was obtained by manually counting vehicles as displayed on the video tape made of the actual run during the 7:30 to 9:00 a.m. interval. The ground truth value was compared with the counts from the detector outputs. The figure includes data from the RTMS-X1 microwave presence radar, a TDN-30 Doppler microwave detector, an SDU-300 ultrasonic detector, an inductive loop, the 780D1000 laser radar, and the Autoscope 2003 video image processor.

A wide variation in the vehicle count is present. The best count results were achieved by the inductive loop, followed by the Schwartz laser radar relay output, the Autoscope VIP, and the Sumitomo SDU-300 ultrasonic detector in that order. The two microwave detectors, the side-looking RTMS and the Whelen TDN-30, showed poor results for this test. The RTMS generally provides better results in the forward-looking orientation. The Whelen TDN-30's problem was likely due to a failure of a rubber seal that allowed water from a number of thunderstorms to seep into the unit. Whelen has since improved the design of their housings and seals and drilled a hole in the bottom of their case to avoid accumulation of moisture.

2.9.4 Sample of Florida Surface Street Results

Figure 17 shows the short term stability of the vehicle count obtained with the Eltec 833 and the RTMS-X1 in lane 2 (middle westbound lane). The data span almost a 6-hour period starting at 3:53 p.m. on September 7. The weather was hot and humid with heavy rain starting about 5:15 p.m., tapering to thunder showers around 5:30 p.m.

The vehicle counts were accumulated over 3-minute intervals, corresponding to the cycle time of the traffic signals at the intersection of SR436 and an exit ramp from the westbound I-4 freeway. The average value of the count difference was -1.94 counts and the standard deviation of the count difference was 2.83 counts. The standard deviation of the percent difference values was 7.22 percent. The 833 consistently undercounted as evidenced by the predominance of negative percent differences when compared with the RTMS counts. This indicates that the Eltec 833 IR detector was either missing some vehicles entirely (due to insufficient detector sensitivity to distinguish the thermal contrast between the vehicle and the road surface), or failing to discriminate between closely spaced vehicles.

2.9.5 Sample of Phoenix Freeway Results

The data in Figure 18 are from November 22, 1993. The run commenced at 1:59 p.m. when traffic was moderate and continued through the peak traffic period. The weather was mild and clear. Vehicle count ground truth was obtained by manually counting vehicles on the recorded video imagery for the 4:00 to 5:00 p.m. interval.

The figure shows vehicle flow in lane 2 (middle westbound lane) as calculated using data from the TDN-30 microwave detector, 833 passive infrared, and Autoscope 2003 video image processor. The flows were computed based on one-minute data integration intervals over a one-hour period between 4 and 5 p.m. for which the ground truth vehicle counts were available. The result of using a one-minute integration interval is a discrete, "spiky" curve. Shorter integration intervals, such as thirty seconds, produce flow values that reflect the micro-scopic movement of individual vehicles and thus may generate a curve that shows higher instantaneous flow rates. Short integration intervals may be required when the maximum peak flow on a roadway is needed.

The flow patterns calculated from these detector data generally agree with one another, although the peak values reported by Autoscope at several instances are greater than those from the other detectors. The effect on the accuracy of the vehicle count over the one-hour interval was minimal, however, as the Autoscope count was only one greater than the ground truth value for the interval.

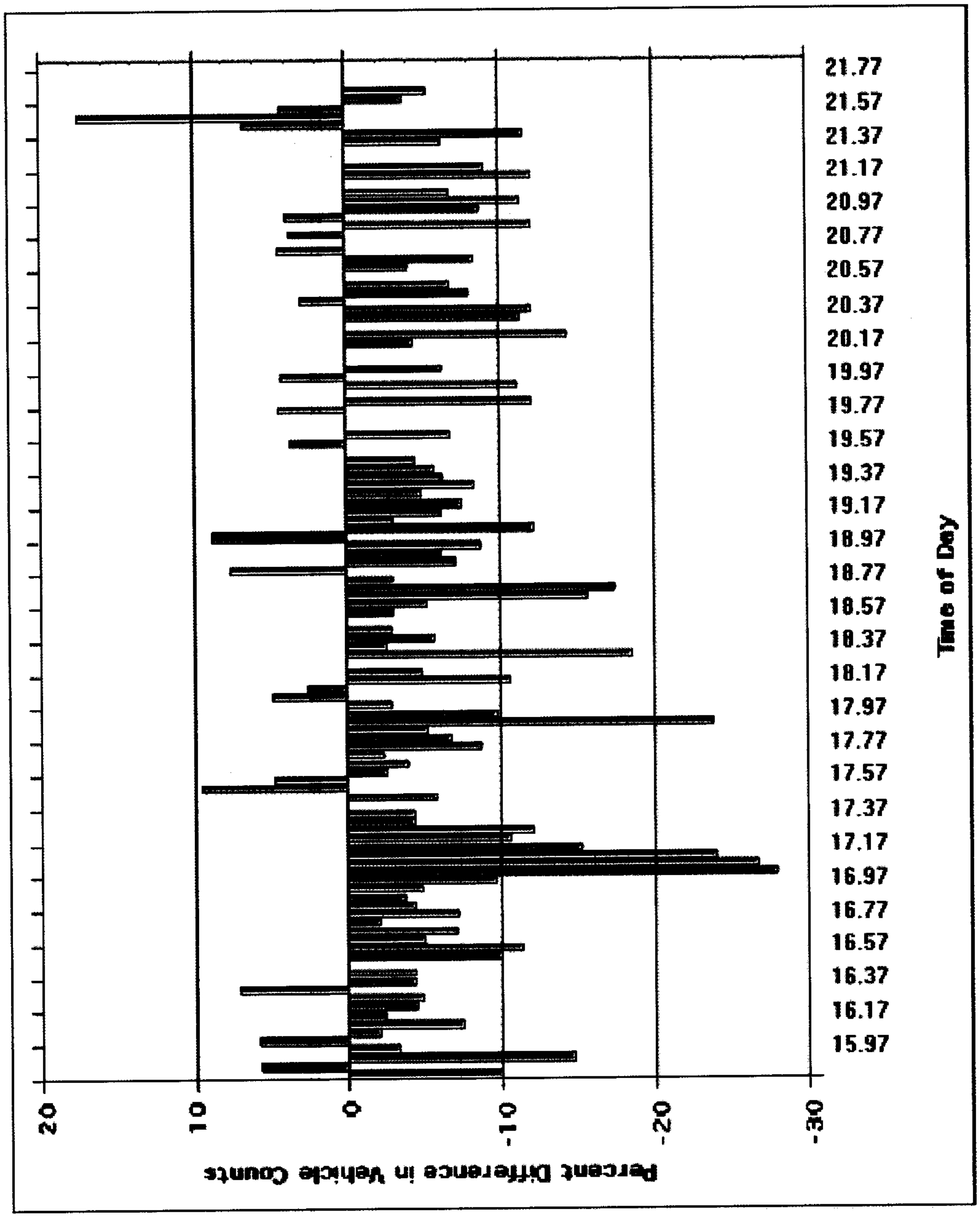


Figure 17. Percentage difference in vehicle counts between Eltec 833 and RTMS-X1 over 3-minute traffic signal cycles at SR436 Florida surface street site

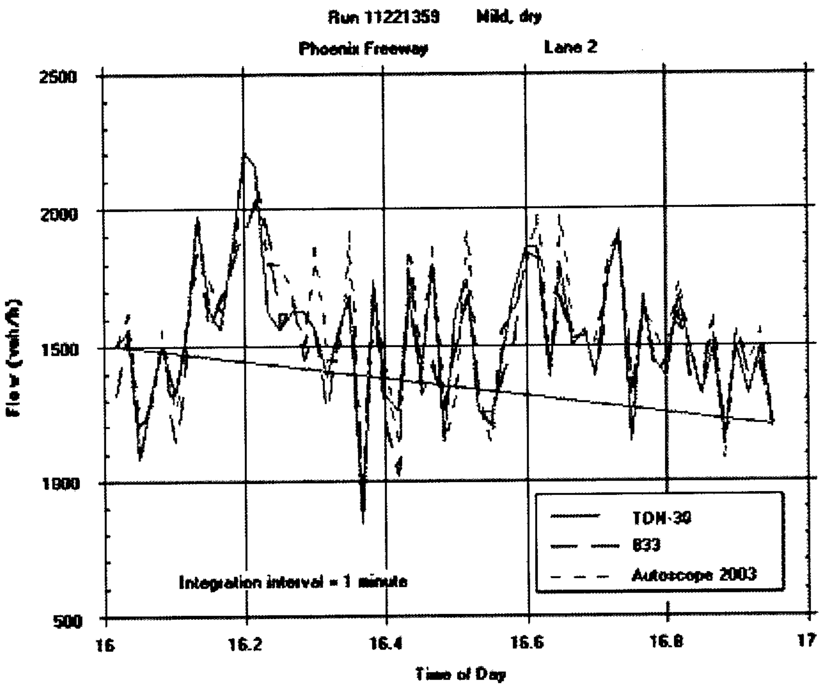


Figure 18. Vehicle Flow in Lane 2 Using Data From TDN-30, 833, and Autoscope 2003 Over 1-Hour Ground Truth Interval at I-10 Phoenix Freeway Site

The EVA VIP was made available for the Summer 1994 detector technology evaluation at Phoenix. Detector counts for the EVA VIP, inductive loop, and RTMS-X1 microwave radar from Run 07281536 are shown in Figures 19 and 20 for lanes 1 and 2, respectively. Lane 1 was the leftmost lane open to all vehicles regardless of passenger occupancy and lane 2 was the middle lane. The temperature was 107oF (41.7oC) at 2 p.m. and 108oF (42.2oC) at 5 p.m. The RTMS microwave radar was used as the basis for count comparison in these graphs because it appeared to be the most accurate vehicle count detector during this run as deduced from the ground truth results. By comparison, the inductive loop in lane 1 overcounted by 6.5 percent, while the loop in lane 2 overcounted by 5.8 percent with respect to the RTMS counts. The EVA, forward-looking RTMS, and the loop were installed to detect vehicles in zones corresponding to overhead detectors with 45-degree (zone 1) or greater (zone 2) incidence angles. The EVA appeared to overcount in lane 1 with respect to the RTMS in daylight and darkness, the overcount being 1.6 percent over the approximately 5-hour run duration. In lane 2, the EVA overcounted until approximately 8:30 p.m. and then undercounted for the rest of the run with respect to the RTMS. In this lane, the total undercount was 3.2 percent. If the run time had been shorter, the overcount in lane 1 attributed to the EVA would be greater, and the undercount in lane 2 would change to an overcount.

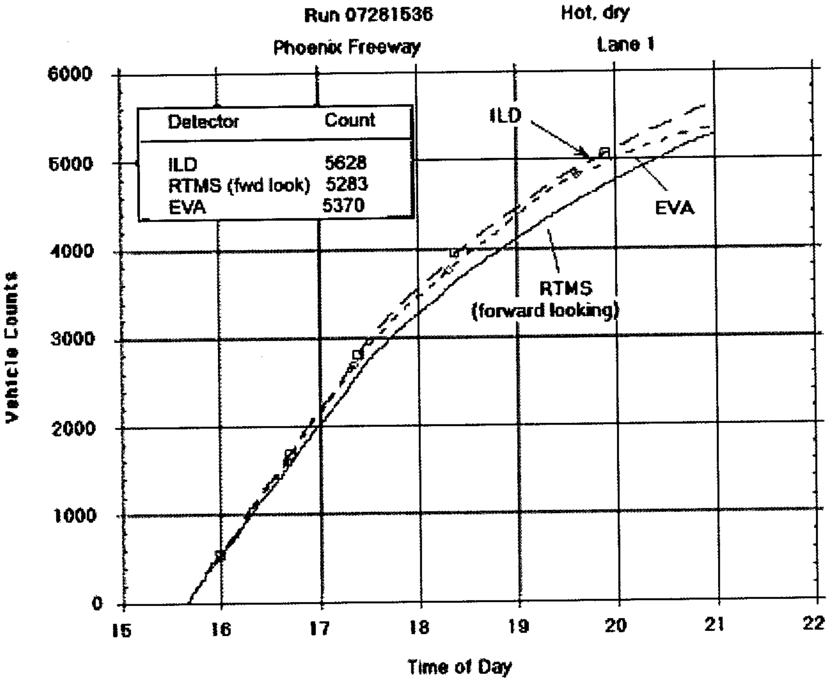


Figure 19. Vehicle counts in detector zones 1 and 2 of lane 1 during Run 07281536 at I-10 Phoenix freeway site

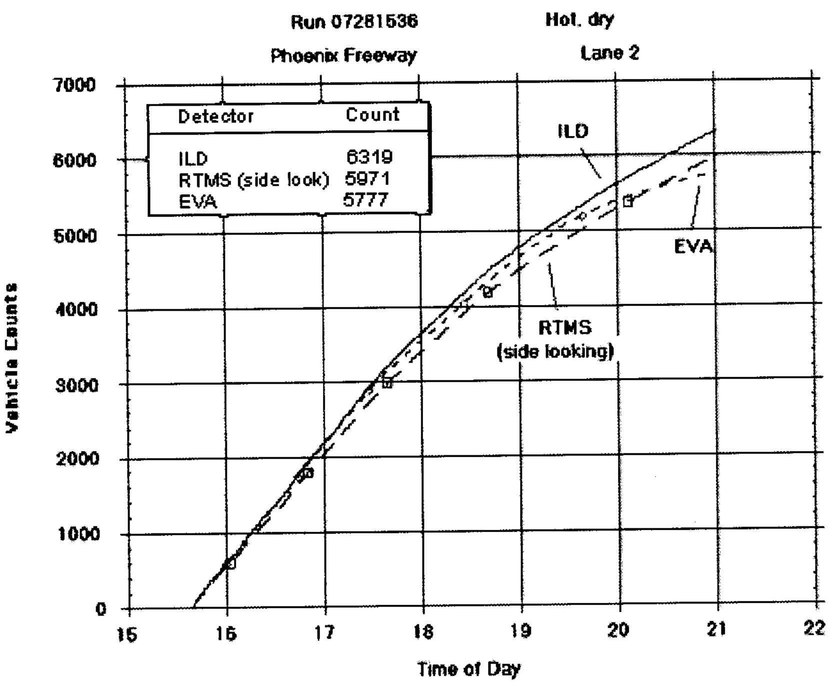


Figure 20. Vehicle counts in detector zones 1 and 2 of lane 2 during Run 07281536 at I-10 Phoenix freeway site

2.9.6 Sample of Tucson Surface Street Results

The Tucson evaluation site had the largest assortment of VIPs, three operating in the visible band and one in the infrared. Traffic counts from two of these runs are shown in Figures 21 through 24. Figures 21 and 22 are from lanes 2 (middle) and 3 (curb), respectively, of Run 04121633 on southbound Oracle Road, while Figures 23 and 24 are from Run 04131703 for the corresponding lanes. Lane 3 had a pair of 6-foot (1.8 m) diameter round loops as well as a pair of 6-foot (1.8 m) square loops.

In Figures 21 and 22, vehicle counts from the CCATS-VIP 2 appear lower than those from the other VIPs when darkness occurs. This is due to the particular algorithm in software version E1.01 supplied with the CCATS-VIP 2 that was tested. The E1.01 algorithm was written to prevent shadows from being recognized as vehicles. The algorithm was not able to distinguish all the dark-colored vehicles from the dark background. This phenomenon was observable in the field on the television monitor that showed the traffic flow along with the vehicle counts as overlaid by the VIP. Traficon has since developed software version 2. In their application of the new software to two of the video recordings containing shadows on the road and nighttime operation, Traficon demonstrated an increase in the identification of true vehicles and, thus, increased the true vehicle count between 9 and 20 percent, depending on the conditions of the run.

Data from the Northrop-Grumman imaging infrared traffic sensor overlaps the detection area from the second square inductive loop in lane 3. The Northrop-Grumman sensor undercounted by 22 percent as compared to the loop. However, this particular model of the imaging infrared traffic sensor was not designed to count individual vehicles. It was designed to give a presence output every one second if one or more vehicles was within its detection zone in the preceding 1-second interval. Thus, if two or more vehicles passed through the detection zone during a 1-second interval, only one event would be registered by the sensor. From observation of the traffic flow, it appeared that multiple vehicles did pass through the sensor's detection zone during some of the 1-second intervals. Additional analysis can be used to verify the more than one vehicle per reporting interval hypothesis by overlaying the vehicle detections onto the video ground truth imagery and examining the correlation of reported and actual events. If the sensor consistently detects the first of two closely spaced vehicles but misses the second, this would indicate that the undercount is indeed due to the particular way the data are processed in the internal algorithms of the sensor. The crisp infrared imagery displayed on the television monitor appears to produce good thermal contrast between the vehicles and the background during day and night operation. This indicates that there is sufficient information in the image to recognize individual vehicles.

The performance of the four video image processors in Run 04131703 is consistent with results from Run 04121633. Figure 23 shows the cumulative vehicle counts for the three visible wavelength VIPs and the second inductive loop in lane 2. These VIPs undercounted, with respect to the loop, by approximately 7 to 10 percent until about 7:00 p.m. as compared with undercounts of 6 to 8 percent the night before. After 7 p.m. the percentage differences between the Autoscope and IDET-100, as compared to the inductive loop, remained fairly constant for the remainder of the run. However, the CCATS-VIP 2 began to miss more vehicle detections after 7:00 p.m. as nighttime darkness occurred. The CCATS reported 18.9 percent fewer counts than did the loop in this run and an undercount of 15.5 percent in the previous night's run. Their updated algorithm should potentially improve upon these results.

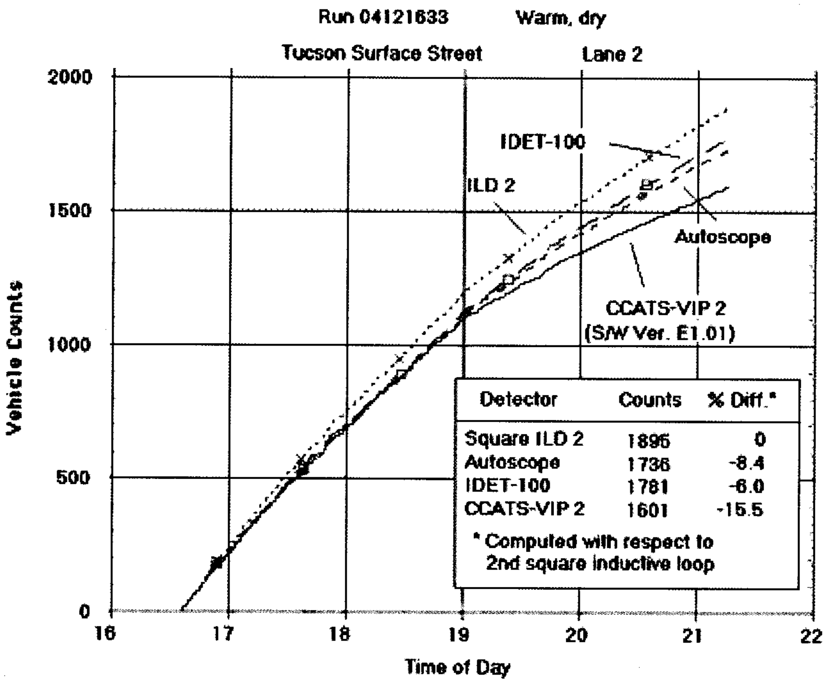


Figure 21. Comparison of vehicle counts in lane 2 from VIPs in Run 04121633 at Tucson surface street site

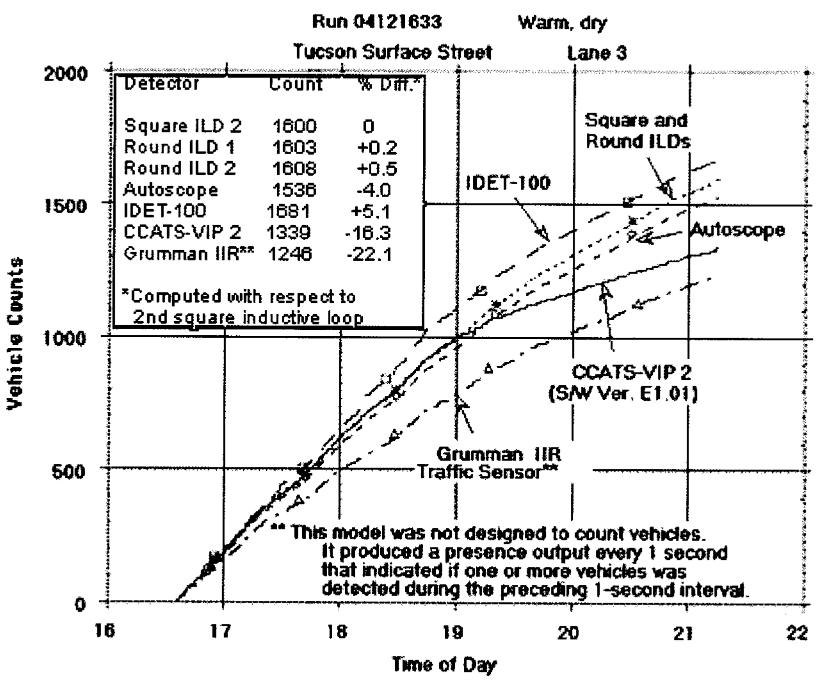


Figure 22. Comparison of vehicle counts in lane 3 from ILDs and VIPs in Run 04121633 at Tucson surface street site

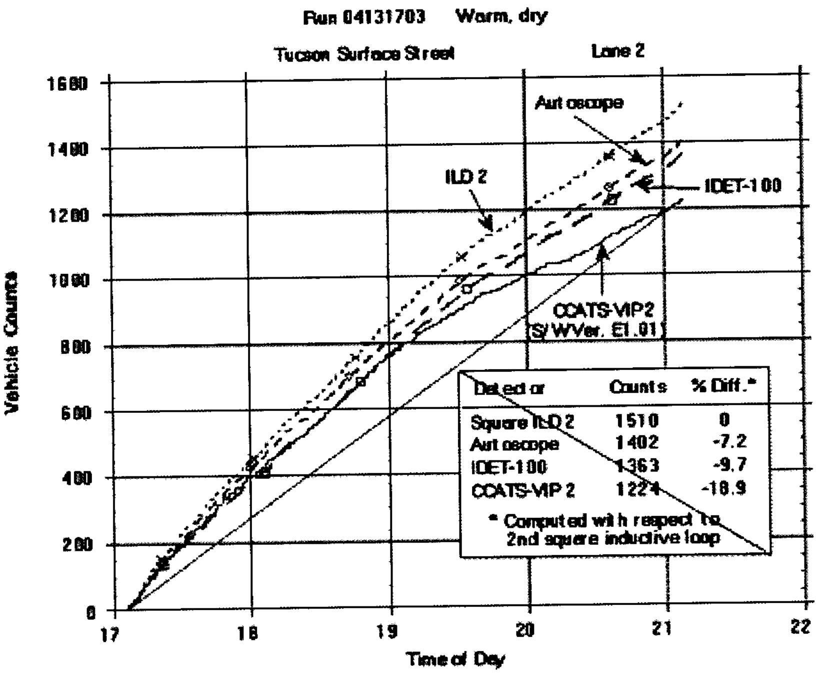


Figure 23. Comparison of vehicle counts in lane 2 from VIPs in Run 04131703 at Tucson surface street site

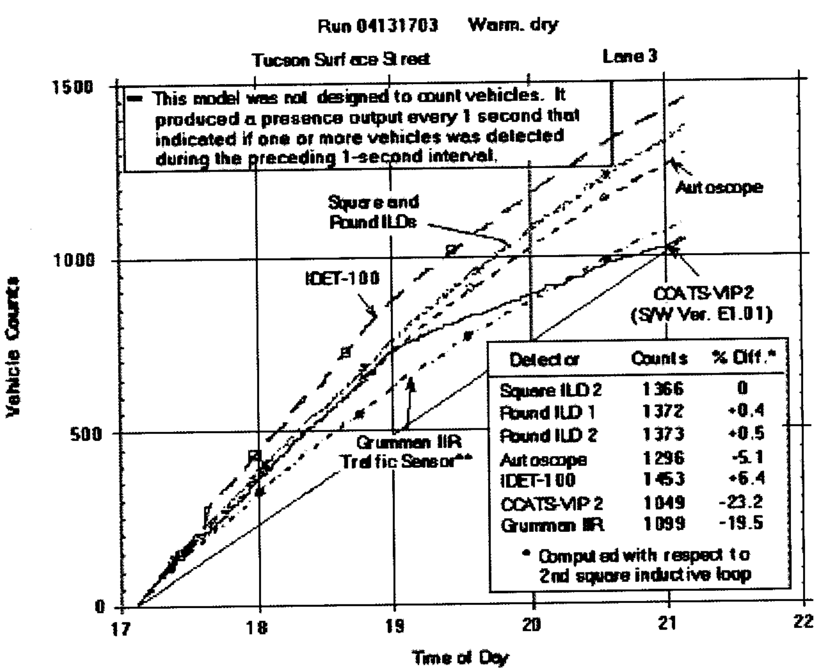


Figure 24. Comparison of vehicle counts in lane 3 from ILDs and VIPs in Run 04131703 at Tucson surface street site

Figure 24 shows lane 3 count results from the same visible spectrum VIPs as were used in monitoring lane 2, as well as from the Northrop-Grumman imaging infrared VIP and the two round inductive loops. The three loops (the second square loop and the two round loops) reported counts within 0.5 percent of each other. The Autoscope count was 5.1 percent below that reported by the second square loop. This result is consistent with the four percent undercount from the previous night's run. Similarly, the IDET-100 overcounted by 6.4 percent as compared to 5.1 percent the night before. Again the counts from the CCATS decreased after 7:00 p.m. The unit reported 23.2 percent fewer counts than the loop as compared to 16.3 percent from Run 04121633. The Northrop-Grumman imaging infrared sensor undercounted by 19.5 percent compared to 22.1 percent recorded in the previous night's run. As explained earlier, the Grumman algorithm evaluated in the field tests was not designed to count vehicles, but rather to give a presence output every one second if one or more vehicles was within its detection zone in the preceding 1-second interval.

2.10 CONCLUSIONS

Off-the-shelf, state-of-the-art detectors obtained from various manufacturers were used to evaluate various detector technologies. Both quantitative and qualitative observations were made regarding how well a particular technology performed relative to others at the field test evaluation sites. Table 6 provides a qualitative summary of which technologies exhibited the best performance with respect to supplying various traffic parameters. These results are based on the limited number of runs reduced so far and the general qualitative opinions gained from using these devices over an 18-month evaluation period. The selection of a detector for traffic management is very much dependent on the specific application. The results obtained in this project may not exactly reflect the performance of newer model detectors, especially those (such as video image processors) that employ software to analyze and report data since software upgrades can significantly affect detector performance.

Table 6. Qualitative assessment of best performing technologies for gathering specific data

Technology	Low-Volume Count	High-Volume Count	Low-Volume Speed	High-Volume Speed	Best In InclementWeather
Ultrasonic	–	–	–	–	–
Microwave Doppler*	✓	✓	✓	✓	✓
Microwave True Presence	✓	✓			✓
Passive Infrared	–	–	–	–	–
Active Infrared	–	–	–	–	–
Visible VIP	✓	✓			–
Infrared VIP					
Acoustic Array	–	–			
SPVDMagnetometer	✓	–	–	–	✓
Inductive Loop	✓	✓	–	–	✓

✓

Indicates the best performing technologies.

– Indicates performance not among the best, but may still be adequate for the application.

No entry indicates not enough data reduced to make a judgment.

* Does not detect stopped vehicles. 2.10.1 Most Accurate Vehicle Count for Low Traffic Volume **2.10.1 Most Accurate Vehicle Count for High Traffic Volume**

Most of the detectors gave good results when used under light traffic conditions. Detectors with multiple outputs or detection zones give the appearance of better performance than do those with only one detection zone because only the most accurate of the outputs was displayed in the reported results. For example, if loop #1 showed better agreement with the ground truth value than loop #2 (for the same lane), then the loop #1 results were presented. Likewise, if a single traffic detector had multiple detection zones, the most favorable of the outputs was used in the plotted results. This affords a greater opportunity for these devices to appear in a favorable light, whereas, a simple detector having a single relay output was represented solely on the basis of that single output.

The ultrasonic and infrared detectors exhibit count accuracies that make them suitable for a variety of applications, but they were typically not among the most accurate. The SPVD magnetometer performed well in low-volume applications, as demonstrated by the zero-percent error over a 2-hour run during snowfall conditions for one of the Minnesota surface-street runs.

Microwave detectors were also well suited to low-volume conditions. The presence-type microwave radar consistently provided better vehicle count results in forward-looking operation than in side-looking orientation. Forward-looking count accuracies to within 1-percent were not uncommon; however, these accuracies were typically provided by only a single detection zone due to the difficulty in confining the detector's elliptical beam footprint to a single lane of traffic. Because of this footprint geometry, only one detection zone tends to be optimally matched to the dimensions of the traffic lane, while the remainder of the zones tend to undercount (in the narrow parts of the beam where the detection zones are not as wide as the lane) or overcount (where the wide part of the beam tends to spill over into adjacent lanes of traffic).

Doppler-type microwave detectors fare well in low-to-moderate traffic volume conditions, where free-flowing traffic consistently provides a component of motion in the detector's viewing direction that is necessary for the operation of these units. However, there can conceivably be traffic management applications where a knowledge of decreasing speeds can be used to infer that stopped vehicles are present even though the Doppler detector does not give an output indication once the vehicle comes to a full stop. Again, care must be taken to ensure that the detector's beam footprint on the roadway is confined to the desired monitoring area.

Some video image processors exhibit counting characteristics similar to microwave detectors. The Autoscope 2003, for example, can be configured to have three separate detection zones per lane (two emulating a pair of inductive loops and a third configured as a speed trap). Data show that count results tend to be optimized for a given zone.

Inductive loops are among the most consistent performers, with count accuracies typically in the 99-percent range. Even so, problems with crosstalk and double- or triple-counting large trucks and tractor-trailer rigs have been seen when reviewing videotapes of the field tests.

2.10.2 Most Accurate Vehicle Count for High Traffic Volume

Many of the same observations made in the previous section apply here as well. However, the electronic hold time of a detector begins to become an important factor when intervehicle gap times decrease. The hold time is the period over which a detector remains in the active state after the initial detection of a vehicle.

For the field tests, the hold time of each device was always set to its minimum value. Increasing the hold time in heavy traffic conditions has a negative impact on count accuracy due to the detector's inability to determine when one vehicle departs the detection zone and another enters. With long hold times, a second vehicle enters the detection zone prior to the falling edge of the pulse created by the first vehicle. This can result in several closely spaced vehicles registering only a single count on a given detector. Although several detectors evaluated were designed with long hold times because of an initial traffic management requirement, devices of similar types can certainly be redesigned with shorter hold times as new applications arise.

2.10.3 Most Accurate Speed for Low Traffic Volume

Speed accuracy is a difficult parameter to assess due to the challenge of obtaining the true speeds against which to compare the detector speed outputs. Some detectors compute speeds based on average vehicle lengths. Such devices may yield acceptable accuracies for average vehicle speed over long time intervals, but not for applications that require speeds over short, tactical time intervals or speeds on a vehicle-by-vehicle basis. The latter requirement favors the implementation of detectors that make direct speed measurements, or pairs of detectors that can be used in a speed-trap configuration.

The simplest and most accurate way to measure speed is with a detector that provides it directly, such as a Doppler microwave detector. Doppler devices require a component of vehicle motion in the direction of travel monitored by the detector. Since free-flowing traffic is normally available in low-volume conditions, a Doppler device would seem a logical choice for such an application. Speed as measured by Doppler microwave detectors usually agreed within 2 to 3 mi/h (3.2 to 4.8 km/h) with readings from the speedometers of the probe vehicles. However, the imprecision associated with a human observer recording these values from an analog speedometer of unknown accuracy yields, at best, a reference value and not absolute truth.

Some detectors that provide speed outputs could not be evaluated with the single probe vehicle. These units output average speed data collected over a larger integration interval and, as such, do not give information on a per vehicle basis. Among these devices were several video image processors and the RTMS-X1 microwave true-presence radar.

The selection of a preferred speed-measurement technology is application-dependent. If the requirement is for a unit that will supply average speed, occupancy, or some other statistically derived parameter, the choice should be one of the sophisticated detection systems employing enough processing capability to accurately compute the desired parameter(s). Conversely, if the data are required on a per vehicle basis, the choice narrows to devices that output the desired parameters in real time as they are acquired. Certainly the more sophisticated units, such as video image processors, multi-zone radars, and laser radars, have the ability to output data on a per vehicle basis as they must measure the characteristics of individual vehicles in order to produce their statistical outputs. However, the cost of these units will likely dictate that they be utilized only for applications that require statistical data or where their cost can be justified on an equivalent per detector basis or through life-cycle cost considerations.

2.10.4 Most Accurate Speed for High Traffic Volume

Many of the same points made for low traffic volume apply here as well. The main difference in requirements between low-and high-volume applications stems from the change in vehicle speeds. Vehicles in low-volume conditions are likely to be free-flowing and unconstrained in their movements, while vehicles in high-volume conditions, where the roadway is at or near its designed capacity, will be restricted in their speed. When the traffic demand exceeds the capacity of the roadway, speeds will obviously decrease. If the speeds slow significantly and bumper-to-bumper traffic conditions ensue, then Doppler detectors will not perform when the vehicle speed is below approximately 3 mi/h (4.8 km/h). In some applications, this may not be of concern as the necessity for zero speed measurement may decrease once the traffic flow falls below some fixed threshold.

2.10.5 Best Performance in Inclement Weather

The detectors that seemed the most impervious to inclement weather conditions were the microwave detectors. No appreciable change in performance was noted during conditions such as rain, snow, wind, and extreme cold or heat. The magnetometers performed well in the snow during the Minneapolis surface street tests. The inductive loops, when properly installed, performed reliably through a broad spectrum of weather conditions.

The technologies with the greatest extreme weather limitations include the ultrasonic, infrared, acoustic, and video image processors. This is not due to any flaw in the design of these units, but rather to physical limitations caused by weather-related phenomena, such as gusty winds (greater than 56 mi/h [>25 m/s] in the case of the Doppler ultrasound detector) or the presence of atmospheric obscurants. However, even these devices are relatively unaffected by inclement weather conditions when operating at the short ranges typically associated with their normal traffic management applications.

2.10.6 Microscopic Single-Lane Versus Macroscopic Multiple-Lane Data

Several of the detectors were better suited for collecting data that characterized individual vehicles in multiple lanes, while others were better for gathering data from groups of vehicles in multiple lanes. The detectors best suited for acquiring microscopic (individual vehicle) data over multiple lanes were the true-presence microwave radar and the video image processors. Those useful for collecting macroscopic (groups of vehicles) data were the wide-beam Doppler microwave detectors, true-presence microwave radar, and the video image processors. The selection of a particular detector is highly dependent on the specific application.

3. REFERENCES

1. *Detection Technology for IVHS . Task A Report: Development of IVHS Traffic Parameter Specifications,* Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1994.
2. L.A. Klein, N.A. Rantowich, C.C. Jacoby, and J. Mingrone, "IVHS Architecture Development and Evaluation Process,7quot;, *IVHS Journal*, Vol. 1(1), 13-34, 1993.
3. A. Gelb, *Applied Optimal Estimation*, MIT Press, Cambridge, MA, 1980.
4. R.D. Kuhne, "Freeway Control Using a Dynamic Traffic Flow Model and Vehicle Reidentification Techniques," Paper 91-0419, TRB 70th Annual Meeting, Wash., D.C., Jan. 1991.
5. *Detection Technology for IVHS . Task F Report: Vehicle Detector Field Test Specifications and Field Test Plan*, Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1994.
6. L.A. Klein, M.S. MacCalden, Jr., and M. Mills, "Detection Technology for IVHS," in *Proc. of the IVHS AMERICA Third Annual Meeting,* Wash., D.C., April 1993.
7. L.A. Klein, "Traffic Parameter Measurement Technology Evaluation," in Proc. *IEEE-IEE Vehicle Navigation and Information Systems Conference-VNIS '93,* pp. 529-533, Ottawa, Canada, Oct. 1993.
8. L.A. Klein and M.K. Mills, "Evaluation of Modern Traffic Detector Technologies for IVHS Applications," *Proc. NATDAC '94,* Sponsored by CT DOT and FHWA, September 18-22, 1994.
9. L.A. Klein, M.R. Kelley, and M.K. Mills, "Evaluation of traffic detection technologies for IVHS," *SPIE Vol. 2344 Intelligent Vehicle Highway Systems,* pp. 42-53, 1994.

10. L.A. Klein, M.R. Kelley, and M.K. Mills, "Traffic detection technologies for a modern transportation infrastructure," *SPIE Vol. 2592 Collision Avoidance and Automated Traffic Management Sensors,* 1995.
11. *Detection Technology for IVHS . Task D Report: Detector Selection*, Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1994.
12. *Detection Technology for IVHS . Task C Report: Vehicle Detector Laboratory Test Specifications and Test Plan,* Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1993.
13. *Detection Technology for IVHS . Task E Report, Parts I, II, and III: Vehicle Detector Laboratory Test Results,* Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1993 and 1994.
14. *Detection Technology for IVHS . Task B Report: Field Test Site Selection,* Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1993.
15. *Detection Technology for IVHS . Task L Final Report,* Federal Highway Administration Contract DTFH61-91-C-00076, U.S. Department of Transportation, Wash., D.C., 1995.

APPENDIX A. TABLE OF CONTENTS OF TASK L FINAL REPORTTable of Contents1. Scope of the Program

5. Theory of Operation of Detector Technologies

6. Task C Summary: Develop Vehicle Detector Laboratory Test Specifications and Laboratory Test Plan

Appendix XXXIV. The Netherlands Organization for Applied Scientific Research, Spectrum Allocation for ITS: *The World ITS playing field*, (Jan 28, 2015).

TNO innovation for life

Spectrum allocation for ITS

From out of the EU perspective

Paul Spaanderman
With support from Friedbert Berens

TNO innovation for life

The World ITS playing field

Traffic Information ← → Traffic Safety

JAPAN Tolling 5.8GHz

IP based 3-5G networks) ← → ITS-5.8GHz, ITS-700MHz

USA

IP based 3-5G networks) ← → ITS-5.9GHz

Europe Potential Issue with interference from CEN-DSRC 5.8GHz

IP based 3-5G networks) ← → ITS-G5-5.9GHz and ITS-63GHz

Korea Potential Issue with interference with 5.8GHz ITS and Tolling

IP based 3-5G networks) ← → ITS-5.9GHz Broadcast Reply

China Potential Issue with interference from CEN-DSRC 5.8GHz

IP based 3-5G networks) ← → ITS-5.9GHz under discussion

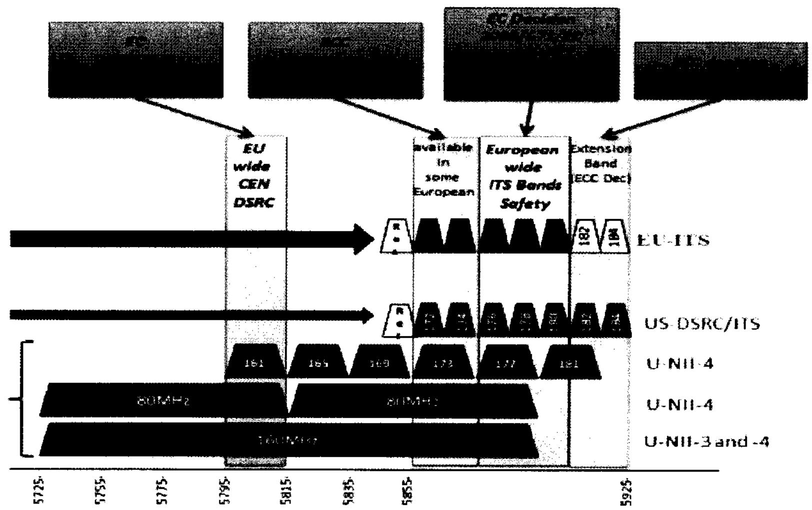
Australia & New Zealand

IP based 3-5G networks) ← → ITS-5.9MHz

DSRC 5.9GHz (USA) and ITS-G5 5.9GHZ (EU)

Europe
USA **Alignment**

Use of the ITS Spectrum by WiFi and GSM ➔ITS-5.9GHz



Paul Spaanderman
Spectrum allocation for ITS
TNO innovation for life

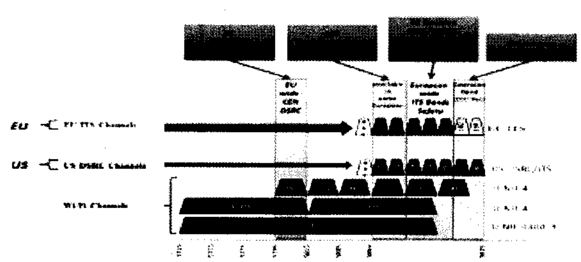
ITS Spectrum in Europe

Europe Potential Issue with interference from CEN-DSRC 5.8 GHz

IP based 3-5G networks)🡐 ➔ITS-G5-5.9GHz and ITS-63GHz

	Frequency range [MHz]	Usage	Regulation	Harmonized standard
ITS-G5A	5 875 to 5 905 MHz	ITS road safety related applications	Commission Decision (ECC/DEC/(08)01), (2008/671/EC)	EN 302 571
ITS-G5B	5 855 to 5 875 MHz	ITS non-safety applications	ECC Recommendation (ECC/REC/(08)01)	EN 302 571
ITS-G5D	5 905 to 5 925 MHz	Future ITS applications	ECC Decision (ECC/DEC/(08)01)	EN 302 571
ITS-63GHz	63000 to 64000 MHz	Future ITS (BRAN, WLAN interest)	Commission Decisions (1999/5/EC)	EN 302 567

- Current legislation and in face of the market deployment of ITS-G5 systems in 2015 channel allocation and the deployed bandwidth (10 MHz) in the ITS systems can no longer be changed. Mitigation techniques relying on reallocating spectrum can no longer be considered. **IEEE TigerTeam incorporates it in there recommendation. Beginning next Month IEEE VOTING! Final European mitigation agreement in 2016?!**



- **The allocation for the ITS 63-64 GHz band is under discussion as WLAN is interested. ETSI TC BRAN is reviewing the EN 302 567 ITS community has to express ITS needs 62-64 GHz. Needs need to be expressed towards ETSI TC BRAN but also to EU commissions Move and Connect**

ITS Spectrum in Europe in relation to Asia

Europe

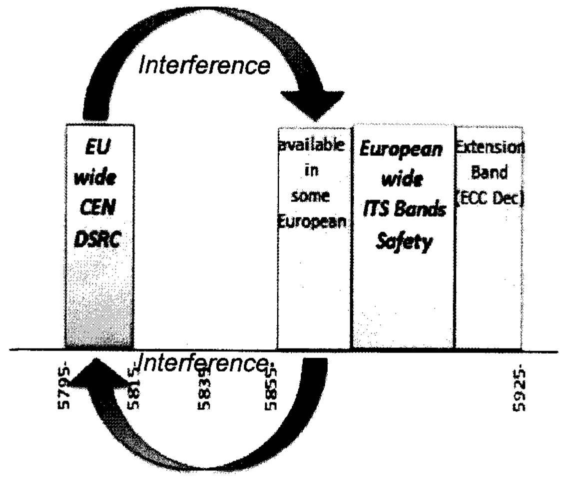
Issue with interference between CEN-DSRC 5.8 GHz and ITS-G5 5.9 GHz

TS 102 792 v1.1.1 was published providing 3 different optional Mitigation methods.

Proposed change is to 2 options only
1.CEN-DSRC signal detector
2.Geographical position database
Both options shall include the CAM protection zone message in addition to handle compatibility.

No consensus yet between stakeholders

Evaluation of technical implementations in Europe expected by 2016-2017 to confirm Coexistence works.



Paul Spaanderman
Spectrum allocation for ITS
TNO innovation for life

World Generalized Summary

Europe **Coexistence between CEN-DSRC (5.8GHZ) and ITS-G5 (5.9GHz) To be solved**

Opportunity

World Wide Harmonised
Spectrum for ITS safety at 5.9GHz

World Wide Threats from WiFi and LTE
Into licensed exceptions bands, IEEE voting

World Wide Awareness usage Cooperative-ITS
- Deployment to show use of spectrum
- Clarification of required bandwidth needed

Any Questions?

Paul Spaanderman paul.spaanderman@tno.nl
ps@paulsconsultancy.com

With support from:
Friedbert Berens friedbert.berens@me.com

Thank you

Appendix XXXV. Michigan Department of Transportation and Center for Automotive Research, *Global Harmonization of Connected Vehicle Communication Standards* (Jan. 12, 2016) ("Global Harmonization of Connected Vehicle Communication Standards").

Michigan Department of Transportation

CENTER FOR AUTOMOTIVE RESEARCH

Global Harmonization of Connected Vehicle Communication Standards

January 12, 2016

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Intelligent Transportation System (ITS) developers envision deploying infrastructure-augmented connected vehicle systems, also known as Cooperative ITS (C-ITS), to improve the safety, mobility, and sustainability of transportation systems across whole networks. Connected-ITS applications combine traditional aspects of connected vehicle systems and ITS infrastructure. For C-ITS to function most effectively, interoperability between the ITS infrastructure and vehicle equipment is needed. Automakers and infrastructure operators must deploy equipment conforming to a harmonized set of standards. Such cross-organizational standards usually are developed through independent standards-development organizations (SDOs) in coordination with effected government and private interests.

Currently, efforts are underway to develop "harmonized" connected vehicle standards so that automakers, governments, and technology developers can adopt analogous conceptual and technological frameworks across markets. C-ITS stakeholders widely believe that such harmonization of ITS standards will accelerate the deployment of C-ITS systems across the globe by leveraging economies of scale for research, development, and manufacturing activities. The accelerated deployment of C-ITS applications could have broad public benefit; therefore, technologies are being developed with the intent of improving the safety, mobility, and efficiency of the transportation system. This potentially broad social benefit has encouraged the U.S. Department of Transportation (USDOT) to coordinate with international agencies in pushing for the greatest possible harmonization of C-ITS standards.

While public transportation agencies are encouraging internationally harmonized C-ITS, standards-development is primarily a private-sector activity. Even federal agencies, such as USDOT, must typically wait for appropriate standards to be developed by independent SDOs; only when standards are formally adopted by SDOs can they be effectively integrated into policy. Regional governments such as Michigan Department of Transportation (MDOT) may have eventual authority over C-ITS infrastructure, and thus have some interest in C-ITS standardization. However, it is difficult to envision how regional governments could have much direct influence over standards development or harmonization processes. If regional governments have well-defined and specific insight to contribute to ongoing standards developments and harmonization activities, they may consider assigning knowledgeable representatives to participate in such activities.

Otherwise, regional governments are generally involved in the eventual *implementation* of adopted standards. Until USDOT successfully adopts a nationwide C-ITS policy including specific standards, state transportation agencies are generally relegated to observer status as SDOs, industry groups, and national governments work towards standards-harmonization and adoption.

The Michigan Department of Transportation is positioned to be a leading adopter of connected vehicle technology if/when USDOT adopts and implements a standardized connected vehicle platform. MDOT has participated in several connected vehicle research and test-bed projects, including the installation of roadside infrastructure conforming to the latest available standards. While MDOT is not in a position to directly influence the development or harmonization of connected vehicle standards, MDOT will sustain a leadership position by actively following standards development and harmonization processes and maintaining in-house expertise on the latest advancements in standards development.

1 INTRODUCTION

Stakeholders in many nations across the globe believe that connected vehicle (CV) systems, also known as Cooperative Intelligent Transportation Systems (C-ITS), have the potential to improve transportation systems in terms of safer and more efficient transportation. Deploying connected vehicle systems would be easier if manufacturers could minimize variations between markets. Having a common hardware and software module (e.g., chip sets and security foundation) is high priority as it translates to cost savings for the manufacturers.[1] To date, stakeholders have been trying to harmonize the equipment and architectures so that CVs can be developed and deployed globally based on a set of standards harmonized to the greatest extent feasible.

Connected vehicles require consistent standards to protocols to work internationally. For example, international harmonization is needed for cross border operations and requires government level coordination.[2] Intercontinental harmonization may also decrease costs because of economies of scale. Main developments are emerging from the USA, Europe, Japan and South Korea. While there are memorandums of understanding between some of these regions and harmonization efforts in place, the result is that there are different C-ITS platforms and communication protocols emerging that correspond with different regions.

With harmonization, automakers could use a single system, rather than installing different systems for vehicles being sold in different markets. Using information gathered from available literature and expert interviews, this report discusses harmonization efforts, including specific areas of focus, stakeholders involved, and various standards being considered. The report also discusses the implications and opportunities these harmonization efforts present for Michigan and Michigan Department of Transportation (MDOT).

[1] Bishop 2013.
[2] VIIC 2013.

2 DEFINING CONNECTED VEHICLE SYSTEMS

Various uses of the term "connected vehicle" may refer to a variety of different types of connected vehicle systems. Connected vehicles include a wide variety of platforms using different communication and data standards for a range of applications. The scope of this report is limited to a specific category of connected vehicle systems often referred to as C-ITS.[3] C-ITS systems require central coordination between vehicles and infrastructure. Intelligent Transportation Systems (ITS) developers envision deploying C-ITS systems to improve the safety, mobility, and sustainability of transportation systems. Such systems must generally be coordinated by a central government agency. In the United States, C-ITS connected vehicle research, development, and regulations are led by the ITS Joint Program Office (ITS JPO) within the Office of the Assistance Secretary for Research and Technology (OST-R) and the National Highway Traffic Safety Authority (NHTSA) of the U.S. Department of Transportation (USDOT).

2.1 CONNECTED VEHICLE APPLICATIONS

There are three broad categories of communication-based automotive applications of connected vehicle systems. These applications present varying characteristics themselves: [4]

- Safety-oriented (e.g., stopped or slow vehicle advisor, emergency electronic brake light, V2V post-crash notification, road feature notification, and cooperative collision warning)
- Convenience-oriented (e.g., congested road notification, traffic probe, free flow tolling, parking availability notification, and parking spot locator)
- Commercial-oriented (e.g., remote vehicle personalization/diagnostics, service announcement, content download, and real-time video broadcasts)

Different applications have different networking criteria and network attributes, as summarized in Table 1.

---

[3] Our scope omits non-ITS connected vehicle systems such as infotainment, fleet telematics, etc.

[4] *Vehicular Networking* (2010).

TABLE 1: CONNECTED VEHICLE APPLICATION ATTRIBUTES[5]

Application Attributes	Description	Choices
Channel frequency	What channel does the application use?	DSRC-CCH, DSRC-SCH, Wi-Fi
Infrastructure	Is infrastructure required?	Yes, No
Message time-to-live	How far do messages propagate?	Single-hop, Multi-hop
Packet format	What type of packet is used?	WSMP, IP
Routing protocol	How are messages distributed?	Unicast, Broadcast, Geocast, Aggregation
Network protocol initiation mode	How is a network protocol initiated?	Beacon, On-demand, Event-triggered
Transport protocol	What form of end-to-end communication is needed?	Connectionless, Connection-oriented
Security	What kind of security is needed?	V2V security, V2I security, Internet security

Other criteria that can be used to classify applications include:[6]

- Application trigger condition: periodic, event-driven, and user-initiated
- Recipient pattern of application message: one-to-one, one-to-many, one-to-a-zone, and many-to-one
- Event lifetime: long or short
- Event detector: single host or multiple hosts

Recently, vehicle to vehicle/infrastructure (V2X) communication-based applications have attracted more attention from industry and governments in the United States, Europe, Japan, and Australia because of their unique potential to address vehicle safety, traffic efficiency improvements, and commercial-oriented applications. In the next section we will discuss characteristics of connected vehicle communications systems.

2.2 CONNECTED VEHICLE COMMUNICATION SYSTEMS

WIRELESS VEHICULAR COMMUNICATIONS

There are varieties of wireless technologies in a modern vehicle, such as wireless AM/FM and satellite radio, multi-media device USB, Bluetooth, Wi-Fi, and remote direct-access telematics (cellular 2G-4G). Dedicated Short Range Communications (DSRC) technology supports both vehicle-to-vehicle

[5] *Vehicular Networking* (2010). *Note: Packet format generally expected to be WAVE Short Message Protocol (WSMP) for safety and convenience, and IP for commercial applications.*
[6] *Vehicular Networking* (2010).

(V2V) and vehicle-to-infrastructure (V2I) applications. Figure 1 shows the variety of utilized vehicle commutations, navigation and active sensors that are available.

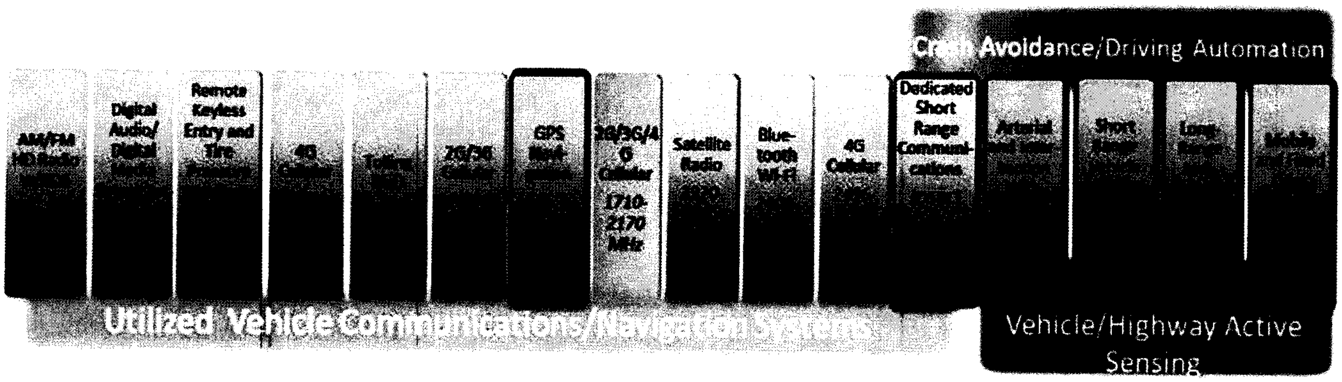


FIGURE 1: VEHICLE AND INFRASTRUCTURE COMMUNICATIONS, NAVIGATION, AND ACTIVE SENSING TECHNOLOGIES[7]

The classification of applications implies network design principles, as illustrated in Figure 2.

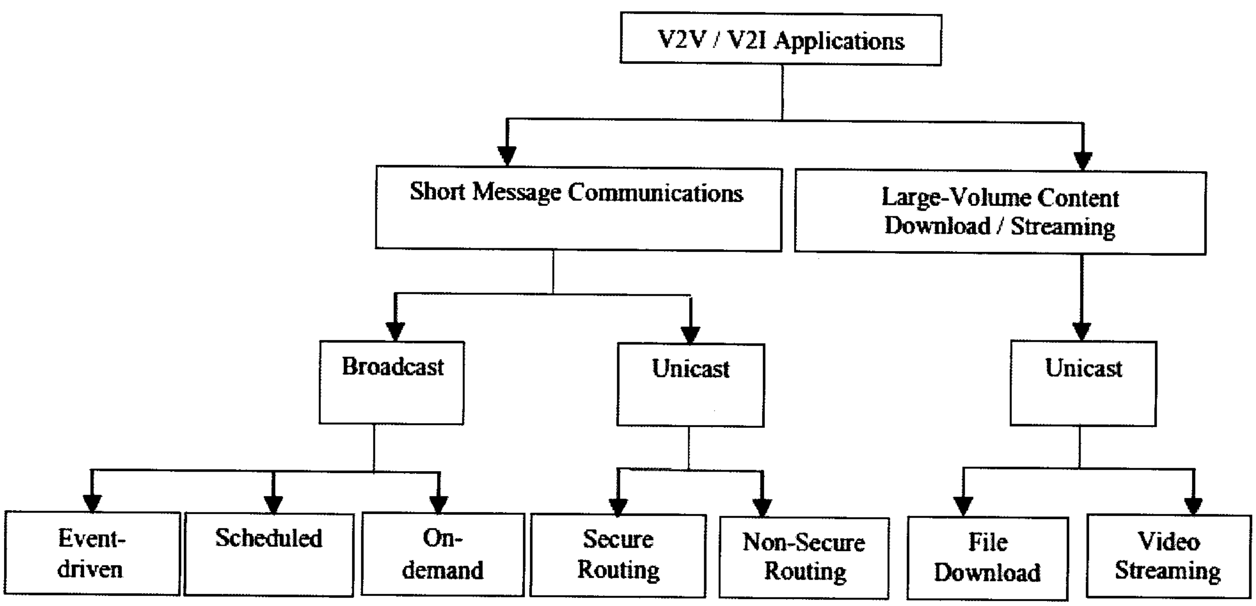


FIGURE 2: CLASSIFICATION FROM THE PERSPECTIVE OF NETWORK DESIGN[8]

---

[7] Source: ITS America 2015.
[8] Source: *Vehicular Networking* 2010.

Conceptualization of wireless protocol functions into seven-layer model as shown in Figure 3:

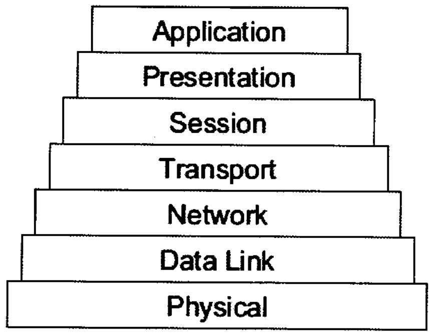


FIGURE 3: OSI ITU-T X.200 1994 SEVEN-LAYER MODEL

Standards activities related to layers:

- Layer 1 (Physical) and 2 (Data Link): IEEE 802.11 wireless, ISO 11898 CAN
- Layer 3 (Network): IETF RFC 1122 1989 Internet protocol (IP)
- Layer 4 (Transport) and 5 (Session): IETF RFC 793 1981 transmission control protocol (TCP) and IETF RFC 768 1980 user datagram protocol (UDP)

International standard ISO 11898 2007 for vehicle serial data exchange at lower protocol layers is Control Area Network (CAN) over twisted pair. CAN is widely adopted but not mandated.[9] The upper layer portion of CAN protocol implemented on a vehicle is likely manufacturer proprietary.

DSRC SPECTRUM

Spectrum requirements for DSRC networks vary substantially from conventional wireless networks. Most V2I applications (e.g., tollbooth) use 915 MHz unlicensed band. Not all bands are equivalent, as shown below and in Table 2.

- North America is using 5.850-5.925 GHz as DSRC band for ITS (IEEE 802.11p for base layers, IEEE 1609 for middle layers, and SAE J2735 for message set).

[9] Except for certain emissions-related information.

- Europe has agreed on a spectrum around 5.9 GHz to be used across the EU. Though not the exact same as North America, it is sufficiently close that the same chipset could likely be used.
- Japan has over 23 million toll collection devices in the 5.8 GHz band. Japan's Association of Radio Industries and Businesses (ARIB) is studying using this band, as well as 700 MHz band, for V2V. ARIB's standards are significantly different than U.S. and EU standards.

TABLE 2: DSRC BANDS AROUND THE WORLD

Region	Standard	Frequency (GHz)
Europe	EN 12253	5.795–5.815
ITU-R	ITU-R M.1453-2	5.725–5.875
Japan	ARIB T55	5.770–5.850
North America	ASTM E 2213-02	5.850–5.925

VEHICULAR AD HOC NETWORK (VANET)

VANET is a communications system for moving vehicles at high speed, which are equipped with wireless communication devices, together with additional wireless roadside units, enabling communications among nearby vehicles (V2V) as well as between vehicles and nearby fixed equipment (V2I) for safety and non-safety purposes. VANET has become an important communication infrastructure for ITS (Figure 4).

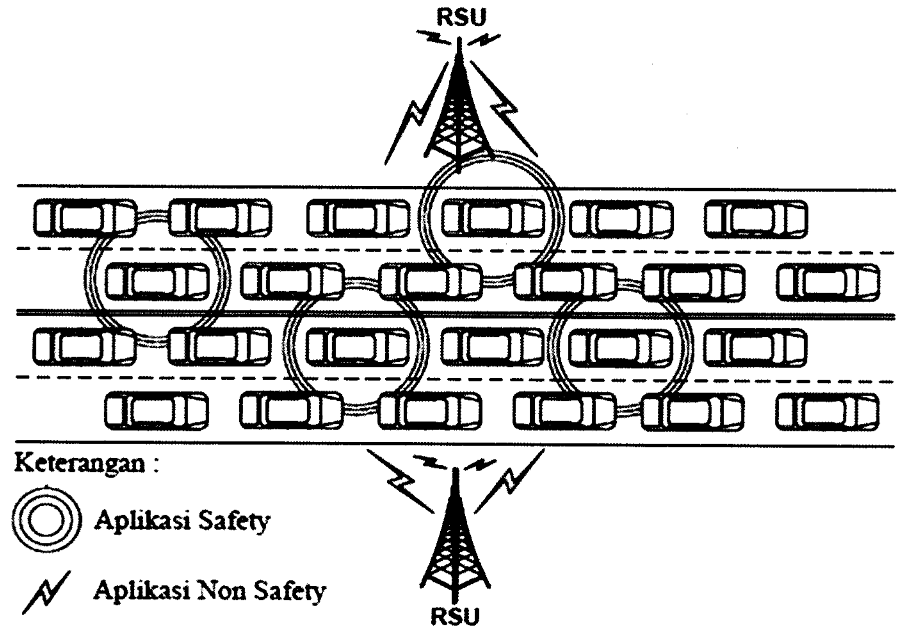


FIGURE 4: VEHICULAR AD-HOC NETWORK[10]

MULTICHANNEL OPERATION

In VANET, one primary issue is Medium Access Control (MAC), which aims to utilize the radio spectrum efficiently, to resolve potential contention and collision among vehicles for using the medium. Multi-channel operation IEEE 1609.4 is a standard of the IEEE 1609 protocol family, which manages channel coordination and supports MAC service delivery.

In the United States, the Federal Communications Commission (FCC) has allocated 75 MHz of DSRC spectrum for vehicular usage at 5.9 GHz in 1999. The bandwidth of each channel is 10 MHz. There are six service channels (SCH) and one control channel (CCH). The control channel is used for system control and safety data transmission. On the other hand, service channels are assigned for exchange of non-safety related data. In addition, these channels use different frequencies and transmit powers.[11]

Multiple channels have been allocated in the 5 GHz spectrum for vehicular communications in United States and in Europe. Due to the limited spectrum, simultaneous communications may occur over nearby channels and be

---

[10] Ahyar et al. 2014.

[11] The FCC and other interests are currently investigating opening up this band for non-licensed uses.

affected by adjacent channel interference (ACI). To protect safety messages delivered on the control channel (CCH), the most likely approach is to prevent the use of adjacent channels with the consequence of spectrum resources wasting.

DEPLOYMENT OPTIONS

Opinions on best approaches to deployment vary widely. Commercial and convenience applications may be implemented before safety applications since safety applications require high penetration rate. Below are some sample options of deployment:

- Standalone system solution: self-contained V2X module built-in to vehicles. This is the most costly solution.
- Navigation system solution: add V2X capability to navigation systems. This might limit growth potential.
- Aftermarket transceiver: may be passive (transmit only) or active. This can be integrated via OBD II or not.

INTEROPERABILITY

Active safety requires thorough, open standards that are stable over decades-long time horizon. Because of regional differences, there is unlikely to be a global agreement on spectrum. But if there could be global agreement on general frequency range (e.g., 'around' 5.8 GHz), channel widths, and over-the-air (OTA) protocol, regional difference may be accommodated with same chipsets but slightly different programming. Bluetooth is a good example of how standardization and cooperation can lead to broad interoperability.

Critical safety messages must be on a particular frequency to minimize packet loss. A message set needs to be standardized, but a standardized message set is not sufficient in itself, to ensure interoperability.[12] In addition to standards, interoperability requires additional 'rules of use,' such as:

- the spectral envelop of channel filtration
- priorities for messages
- creation of intentional interference

In the next chapter we will discuss international connected vehicle harmonization efforts.

[12] Schnaffnit 2010.

3 INTERNATIONAL CONNECTED VEHICLE APPROACHES AND HARMONIZATION EFFORTS

One of the key components of connected vehicle system is the ability for vehicles and infrastructure to be able to talk to one another in an interoperable manner. As such, standards need to be created centrally and adopted widely. Standards are also required in order to ensure connected vehicle components made by different manufacturers work together.

Specifically, for a message to be sent from one vehicle and received by another vehicle, the on-board units (OBUs) in the vehicles must abide by key standards. Similarly, for roadside infrastructure, e.g., an intersection equipped with a roadside unit (RSU) to communicate with passing vehicles, the communication device must be based on the same communication standards as the OBUs in those vehicles. These standards are important to resolve questions such as:

- which entities communicate and to whom (e.g., vehicle, pedestrian, roadside infrastructure, central servers)
- which message set is used within the communication
- what media and channel allocation (if applicable) is used (e.g., 5.9 GHz and the applicable channel allocation)
- which protocol is used (e.g., IPv6)
- what application is implemented and how

A system may include multiple standards as long as they are harmonized and do not impede innovation and performance.[13] Harmonization requires minimizing differences in the technical content of standards having the same scope.[14]

3.1 RELEVANT STANDARDS ORGANIZATIONS

Standards are developed at various levels and by many different SDOs at the global, regional, and national level.[15] Connected vehicles standards are

---

[13] Gouse 2015.
[14] http://www.bptrends.com/publicationfiles/11-05-ART-StandardizationorHarmonizationv-RickenSteinhorst.pdf, accessed April 2015.
[15] Evensen and Csepinszky 2013.

emerging from many countries, including the United States, Europe, Japan, China, and South Korea. Examples of relevant SDOs include:

- International Organization for Standardization (ISO)
- ASTM International[16]
- SAE International[17]
- Institute of Electrical and Electronics Engineers (IEEE)
- National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)
- American National Standards Institute (ANSI)
- European Committee for Standardization (CEN)
- European Committee for Electrotechnical Standardization (CENELEC)
- European Telecommunications Institute (ETSI)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

The International Organization for Standardization (ISO) is an independent, non-governmental membership organization and the world's largest developer of voluntary international standards. ISO is based in Geneva, but it has 163 member nations. The United States participates in ISO through the American National Standards Institute (ANSI).[18]

ISO defines a standard as a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. Standards ensure that conforming products are safe, reliable, and high-quality.[19] International standards can also make industry more efficient and break down trade barriers by harmonizing technical specifications of products and services.[20]

ISO Technical Committee 204 (ISO TC 204) Standards Working Group was established in 1992 for the standardization of information, communication, and control systems in the field of urban and rural surface transportation,

---

[16] Historically, ASTM was an initialism for the American Society for Testing and Materials, but the organization formally changed its name to ASTM International in 2001, to reflect the international nature of the organization.
[17] Historically, SAE was an initialism for the Society of Automotive Engineers, but the organization formally dropped the full moniker in 2006 to reflect the expanded scope of its activities.
[18] http://www.iso.org/iso/home/about.htm
[19] http://www.iso.org/iso/home/standards.htm, accessed April 2015.
[20] http://www.iso.org/iso/home/standards/benefitsofstandards.htm, accessed April 2015.

including intermodal and multimodal aspects thereof, traveler information, traffic management, public transport, commercial transport, emergency services, and commercial services in ITS field. The group is led by ANSI, with 26 countries participating and an additional 27 countries observing.[21]

ISO TC 204 is responsible for the overall system aspects and infrastructure aspects of ITS, as well as the coordination of the overall ISO work program in this field including the schedule for standards development, taking into account the work of existing international standardization bodies.[22] The European Committee for Standardization (CEN) has adopted multiple ISO standards into the European standardized platform for cooperative ITS.

SAE INTERNATIONAL

SAE standards are internationally recognized for their role in helping ensure the safety, quality, and effectiveness of products and services across the mobility engineering industry. The more than 10,000 standards in the SAE database now. Related connected vehicle standards include:

- SAE J2735 Version 2 (2009) Message Set Dictionary. (Needs to be updated to support interoperability.[23] 2015 update pending final acceptance.[24])
- SAE J2945.1 Version 1: Establishes performance requirements, but not standards for accuracy or test procedures. This standard is currently in draft form and the timeline to completion is unclear.[25] Recent connected vehicle projects (such as the Safety Pilot Deployment in Ann Arbor) have had to develop interim performance requirements.[26]

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

IEEE is a leading consensus-building organization that enables the creation and expansion of international markets, and helps protect health and public safety. Within IEEE, the IEEE Standards Association (IEEE-SA) is

[21] http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=54706, accessed April 2015.
[22] http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=54706, accessed April 2015.
[23] Harding *et al.* 2014, pp. 81.
[24] http://www.sae.org/standardsdev/dsrc/usa/, accessed April 2015.
[25] Harding *et al.* 2014, pp. 55.
[26] http://www.its.dot.gov/newsletter/VAD%20Specs.pdf , accessed May 2015.

responsible for the development of international standards related to electrical systems, electronics, and information technology. The U.S. Connected Vehicle Program has extensively adopted IEEE wireless communications standards (IEEE 802.11p and IEEE 1609 series). Related connected vehicle standards include:

- IEEE 1609.4-2010 (network standard)
- IEEE 802.11p-2010 (wireless layer standard)
- IEEE P1609.0/D5.8
- IEEE 1609.2-2013
- IEEE 1609.3-2010
- IEEE1609.12-2012

ASTM INTERNATIONAL

ASTM International (formerly known as the American Society for Testing and Materials) is an international SDO that develops technical standards. ASTM has published several standards associated with ITS and DSRC technologies.[27]

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

The American National Standards Institute (ANSI) is a non-profit organization that facilitates standard development in the United States. ANSI is the official ISO representative for the United States. The ANSI standards store contains ITS standards set by ISO, IEEE, and SAE.[28]

AUTOMOTIVE ELECTRONICS COUNCIL (AEC)

The Automotive Electronics Council (AEC) was originally established by Chrysler, Ford, and GM for the purpose of establishing common part-qualification and quality-system standards. From its inception, the AEC has consisted of two Committees: the Quality Systems Committee and the Component Technical Committee. The AEC Component Technical Committee is the standardization body for establishing standards for reliable, high quality electronic components.[29]

[27] www.astm.org, accessed May 2015.
[28] www.ansi.org, accessed June 2015.
[29] http://www.aecouncil.com/

U.S. NATIONAL TRANSPORTATION COMMUNICATIONS FOR ITS PROTOCOL (NTCIP)

The NTCIP is a joint standardization project of AASHTO, ITE, NEMA, and Office of the Assistant Secretary for Research and Technology of USDOT. The NTCIP is a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. The NTCIP is the first set of standards for the transportation industry that allows traffic control systems to be built using a "mix and match" approach with equipment from different manufacturers.[30]

INTERNATIONAL TELECOMMUNICATION UNION (ITU-T)

International Telecommunication Union (ITU-T) is providing a forum for the creation of an internationally accepted, globally harmonized set of ITS communication standards, to enable the deployment of fully interoperable ITS communication-related products and services into the global marketplace.[31]

EUROPEAN STANDARDS ORGANIZATIONS

Europe has a series of standards organizations that may be involved:

- European Committee for Standardization (CEN)
- European Committee for Electrotechnical Standardization (CENELEC)
- European Telecommunications Institute (ETSI)
- Communications for eSafety Project
- ITS Europe (ERTICO)

CEN, CENELEC, and ETSI have been officially recognized by the European Union and by the European Free Trade Association (EFTA) as being responsible for developing and defining voluntary standards at European level. These standards are often adopted into legal frameworks and thus carry some legal authority.

[30] https://www.ntcip.org/
[31] http://www.itu.int/en/ITU-T/Pages/default.aspx

European Committee for Standardization (CEN)

CEN supports standardization activities in relation to a wide range of fields and sectors including: air and space, chemicals, construction, consumer products, defense and security, energy, the environment, food and feed, health and safety, healthcare, Information and Communications Technologies (ICT), machinery, materials, pressure equipment, services, smart living, transport and packaging.[32] In ITS-related technologies, CEN has coordinated development of standards with ISO to achieve harmonization of standards beyond European states. CEN/ISO has adopted 71 standards designed to facilitate day-1 operability across Europe.[33]

European Committee for Electro-technical Standardization (CENELEC)

CENELEC is responsible for standardization in the electro-technical engineering field. CENELEC prepares voluntary standards, which help facilitate trade between countries, create new markets, cut compliance costs, and support the development of a single European market. CENELEC adopts international standards wherever possible, most notably through collaboration with the International Electro-technical Commission (IEC) under the Dresden Agreement.[34]

European Telecommunications Standards Institute (ETSI)

ETSI produces standards for information and communications technologies, including fixed, mobile, radio, converged, broadcast, and internet technologies. ETSI is officially recognized by the EU as a European standards organization, but ETSI standards are generally globally applicable.[35] Many ETSI standards have been adopted into the CEN/ISO Release 1 set of standards for C-ITS.[36] ETSI developed and adopted a set of standards harmonized with the CEN/ISO Release 1 to facilitate day-1 operability of C-ITS.[37]

In early 2014, ETSI and CEN issued "Release 1" specifications, the basic set of standards for Cooperative Intelligence Transport Systems (C-ITS). The

---

[32] https://www.cen.eu
[33] CEN/ISO 2013.
[34] http://www.cenelec.eu
[35] http://www.etsi.org/about
[36] CEN/ISO 2013.
[37] http://www.etsi.org/technologies-clusters/technologies/intelligent-transport, accessed April 2015.

ETSI and CEN/ISO release 1 comprises 157 standards. These standards were the European SDOs response to a 2009 request (Mandate M/453) from the European Commission.[38]

The technical committees of CEN and ETSI are continuing to develop C-ITS standards and will issue Release 2, which will support the deployment of more complex use cases, enable a large installed base of cooperative systems, and support additional available networks.[39] The technical committees, which involve key stakeholders and experts, draw on Europe's extensive deployment projects, such as COMeSafety, Drive C2X, and eCoMove.[40]

The two SDOs divided responsibility for developing standards. ETSI is focused on developing vehicle-to-vehicle (V2V) communications standards on the 5.9 GHz spectrum, while CEN is focused on the overall framework architecture (platform using multiple communications technologies) and on vehicle-to-infrastructure (V2I) applications related to roadside and traffic management applications.[41]

JAPAN

In Japan, the Japanese Industrial Standards committee (JISC) serves as a lead organization based on the approval of the cabinet. An international standardization committee and several technical committees carry out the international standardization activities for ISO/TC 204 on behalf of the JISC. These activities are led by the Society of Automotive Engineers of Japan (JSAE).

The V2V and V2I communication system compatibility team is one of the technical committees that is responsible for DSRC radio communications used in ITS applications including electronic toll collection (ETC). There are also discussions on standards based on V2V and V2I communications. On the contrary, research and development of applications and communications technologies has been separately, concretely and steadily preceded concerning inter-vehicle communications including V2V and V2I communications.

[38] ETSI 2014.
[39] ETSI. 2013.
[40] Cregger 2014.
[41] CEN and ETSI 2010.

However, strategies for standardization as a whole nation have not been identified in Japan so far.[42]

In terms of bandwidth, 5.8 GHz is used for tolling. 760 MHz band is also being used for DSRC (Toyota). They are not compatible with IEEE 802.11p, and law exists that requires continuity of legacy protocols.[43]

KOREA

Within Korea, two organizations are involved, the Korean Agency for Technology and Standards (KATS), and the Telecommunication Technology Association (TTA) of Korea.

Korean Agency for Technology and Standards

KATS is a government agency in charge of national and international standards in Korea. KATS is a member of ISO, IEC, and the Pacific Area Standards Congress (PASC). KATS objectives include harmonizing Korean industrial standards with international standards, conducting research for standardization, and endorsing international agreements related to standardization.[44]

Telecommunication Technology Association (TTA) of Korea

TTA is a non-government organization (NGO) focused on ICT standardization, testing, and certification. TTA conducts research and establishes new standards for the ICT industry. There are currently eight technical committees, and vehicle ITC, ITS, and location-based services are grouped under the Radio/Mobile Communication committee (TC9).[45]

CHINA

China's standards are developed through formal and informal channels that vary between the type of standards and industries involved. Most national standards are drafted and revised through technical committees (TCs), which are responsible for setting priorities and work plans within their individual

---

[42] Society of Automotive Engineers of Japan (JSAE), ITS Standardization Activities in Japan. 2013. Accessed June 18, 2015. < http://www. jsae.or. jp/index_e.html>.
[43] Bishop 2013.
[44] KATS (2015). Korean Agency for Technology and Standards. Website. Accessed June 2015. <http://www.kats.go.kr/en/main.do>.
[45] TTA. (2015). Telecommunication Technology Association of Korea. Website. Accessed June 3, 2015. <www.tta.or.kr>.

technical standards area and for drafting and revising those standards. TCs fall under the supervision of Standardization Administration of China (SAC), though SAC can designate other agencies and organizations to oversee TC work. For example, the Chinese Electronics Standardization Institute—a research and policy group set up under the aegis of SAC, the Ministry of Industry and Information Technology (MIIT), the Ministry of Science and Technology, and the State Council Information Office—oversees TCs in the electronics sector and plays a large role in setting the industry's standards policy and direction.[46]

China Automotive Technology & Research Center (CATARC) and China National Center of ITS Engineering and Technology are two major research organizations responsible for ITS and connected vehicle related standards. The corresponding agency is National Technical Committee 268 on Intelligent Transport Systems of Standardization Administration of China, which is an active member of ISO/TC204.

China has set aside spectrum (5.795-5.815GHz) for ITS applications - mainly for ETC, traveler information systems, traffic operation, and fleet management. Connected vehicle standards are lag behind the rapid market growth driven by global auto manufactures and domestic telecommunication service providers. For example, Chinese networking supplier Huawei and German car manufacturer Audi Group recently announced a new partnership to jointly explore the future of connected car technology. Huawei's LTE modules can support 2G, 3G and 4G networks, as well as TDD-LTE and FDD-LTE standards.[47]

SINGAPORE

The Information Technology Standards Committee (ITSC) is an industry-led effort that is supported by SPRING Singapore (an enterprise development agency under the Ministry of Trade and Industry) and Infocomm Development Authority (IDA) of Singapore (a statutory board of the Singapore Government). ITSC is an open platform for collaboration between industry and government stakeholders to set technical standards. Among ITSC's many committees is the Intelligent Transport Systems Technical

[46] http://www.chinabusinessreview.com/strategies-for-participating-in-chinas-standards-regime/

[47] http://www.computerweekly.com/news/4500246908/Huawei-and-Audi-team-up-on-connected-cars

Committee (ITSTC), which tracks international ITS standardization efforts. The ITSTC facilitates education, stakeholder communication, and adoption of ITS standards for Singapore.[48]

AUSTRALIA & NEW ZEALAND

Australia and New Zealand are interested in standards and have been monitoring development of standards abroad; however, the two countries are waiting to see how international standards development proceeds before setting their own standards. Due to local spectrum management plans, it is likely that Australia and New Zealand will allocate 50 MHz of the 5.9 GHz band for use in C-ITS, in line with the EU allocation.[49]

3.2 UNITED STATES' CONNECTED VEHICLE PROGRAM

USDOT established the ITS Standards Program in 1996 to encourage adoption of those technologies.[50] USDOT seeks to harmonize the standards related to connected vehicles to reduce cost and complexity of these systems and accelerate their deployment. The ITS Standards Program works with SDOs to develop and test standards, as well as provide relevant information, training, and technical assistance. In the United States, connected vehicle technology standards are primarily released by SAE, IEEE, and NTCIP (Figure 5). The United States is also contributing to the development of standards through other SDOs, such as CEN and ISO.

---

[48] ITSC. Information Technology Standards Committee. Website. Accessed June 3, 2015. <www.itsc.org.sg/ >.

[49] Green 2015.

[50] USDOT. ITS Standards Program. Website. Intelligent Transportation Systems Joint Program Office, Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation. Accessed February 25, 2015. <http://www.standards.its.dot.gov>.

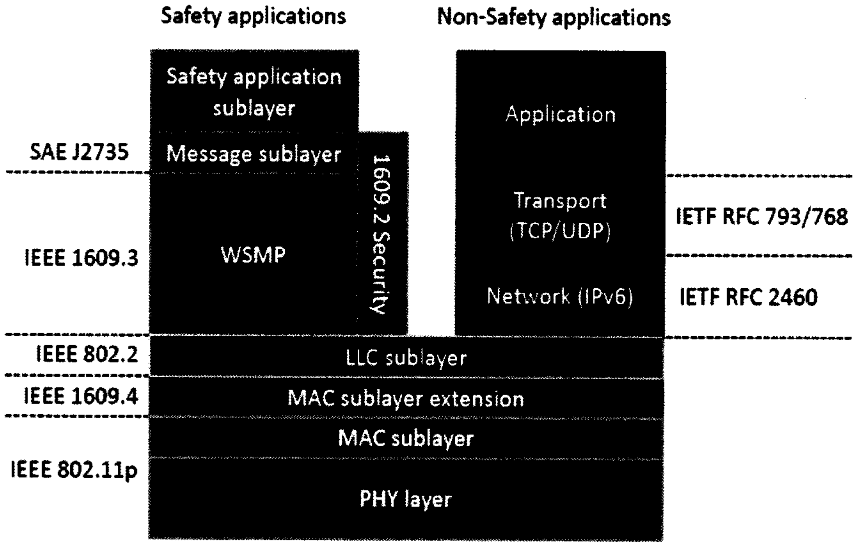


FIGURE 5: USDOT CONNECTED VEHICLE PROGRAM LAYER STANDARDS[51]

WIRELESS ACCESS IN VEHICULAR ENVIRONMENTS STANDARDS

The Wireless Access in Vehicular Environments (WAVE) standards are within the DSRC suite and define a set of protocols, services, and interfaces to enable secure V2V and V2I wireless communications.[52] The WAVE protocol is made up of the combination of IEEE 802.11p and the IEEE 1609 family of standards. IEEE 802.11 is a set of specifications for implementing wireless local area networks (WLAN), and IEEE 802.11p is an amendment that supports vehicular communications. The IEEE 1609 family of standards address the management and security aspects of the network.

DSRC MESSAGE SET

While IEEE defined WAVE/DSRC technology standards, SAE has been responsible for standardizing the message content used in V2V and V2I communications. The SAE J2735 standard specifies a message set applications based on DSRC. Though the standard is focused on DSRC, it has been designed to enable its use by applications based on other wireless communications technologies.[53]

---

[51] Source: Misener 2014.
[52] Ibid. USDOT. (2015).
[53] SAE. (2009). "Dedicated Short Range Communications (DSRC) Message Set Dictionary." Society of Automotive Engineers. November 19, 2009. <http://standards.sae.org/j2735_200911/>.